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HANDBOOK ON IMAGE SCANNING (U)

(4147-68R Task 32)

Supplement 1 to Report No. TO-B 69-16

6 March 1969

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INTRODUCTION

This is an additional guide to the "Applications of Isodensitometry" submitted as an appendix in last year's Final Report. It will be reiterated in part and extended.

Last year's report was intended as a guide to the application of isodensitometry for the recovery of grain-limited photography. In all the sector target analysis performed last year, it was evident that we were working with truly grain-limited photography. The definition of grain-limited photography is that photography in which the lens transfer function falls to zero modulation (or at least intersects the AIM curve) at a considerably lower frequency than that of the film. The problem in recovering grain-limited photography is the random clumping of grains that are of the same order of magnitude as a resolution element. As we have demonstrated, systems incorporating Wiener shaded scanning apertures are beneficial for studying this type of material.

A whole new problem exists when one is interested in lens-limited photography; that is, photography in which the camera lens has an impulse response larger than that of the film (just the opposite of the previous case). The computed Wiener filter in this case is an inverse filter. The scanning aperture that would be used in the image plane is realizable only in a coherent optical system. However, since our system is lens-limited, we would not expect to be bothered a great deal by grain noise. Indeed, this is the case in most, but not all, real-world photographic systems. To conform to actual practice, we shall confine our discussion to non-grain-limited photography.

Before discussing the conditions under which the Image Quantizer should be used, the optimum settings of the IQ, and comparing the IQ and IDT, let us first look at some of the advantages these image scanning instruments offer.

1. Density Quantization – the IDT and IQ both convert density information from a continuous shading from white to black to contours connecting areas of equal density. The density contours more clearly define edges and gradients. The contours that are packed the closest together are indications of the edge location (inflection point). Also, there is the psycho-physical advantage of the contours, which may be thought of as artificial edges that tend to highlight diffuse and low contrast structure. This is the

method in which equi-densitometry reveals low contrast structure that is below the visual threshold. With the four-color IDT, interpretation of the traces is facilitated by the contours' being in color.

2. Grain Integration — With these scanning instruments the impulse response of the instrument is actually the scanning aperture itself. To change the instrument's frequency response capabilities to maximize the signal-to-noise ratio in a given circumstance, therefore, all we need to do is change the aperture. Large apertures integrate noise but reduce resolution. Smaller apertures have just the opposite effect. Wiener shaded apertures have been developed to optimize this tradeoff.

3. Derivative Output — The IQ offers the capability of displaying the one-dimensional derivative of a photographic scene. This can be useful for mensuration purposes. The point of maximum density gradient has been shown to be a good criterion for mensuration, and the IQ derivative printout aids in locating this point. This mode is also useful in outlining the borders of low contrast objects.

4. Use of Paraxial Optics — These scanning systems all utilize imaging optics only in the paraxial region. As the transfer function of imaging optics is always better on-axis than off-axis, the overall quality of images transferred through these scanning instruments is improved.

WHEN TO USE ISODENSITOMETRY

THE ISODENSITRACER®

The main advantage of the IDT lies in its four-color printout, which greatly facilitates identifying the equidensity contours. The IDT is particularly well suited for analyzing imagery for which it is important to follow subtle changes in density. An example of this might be a case where small density changes in the image of a body of water might be indicative of depth fluctuations. Another type of situation where the IDT has proved useful is in assisting in the analysis of low-contrast imagery. We stress that in such cases the IDT trace should be viewed in conjunction with an enlarged image of the scanned area. The IDT trace may indicate structure of interest that could be overlooked in simply viewing the image or, conversely, it may give information about regions of interest in the image that cannot be obtained by simply viewing the image. An IDT trace alone can give misleading information. For example, shadows may be interpreted as discrete objects. It is important to use the IDT trace and a real image to complement each other.

THE IMAGE QUANTIZER

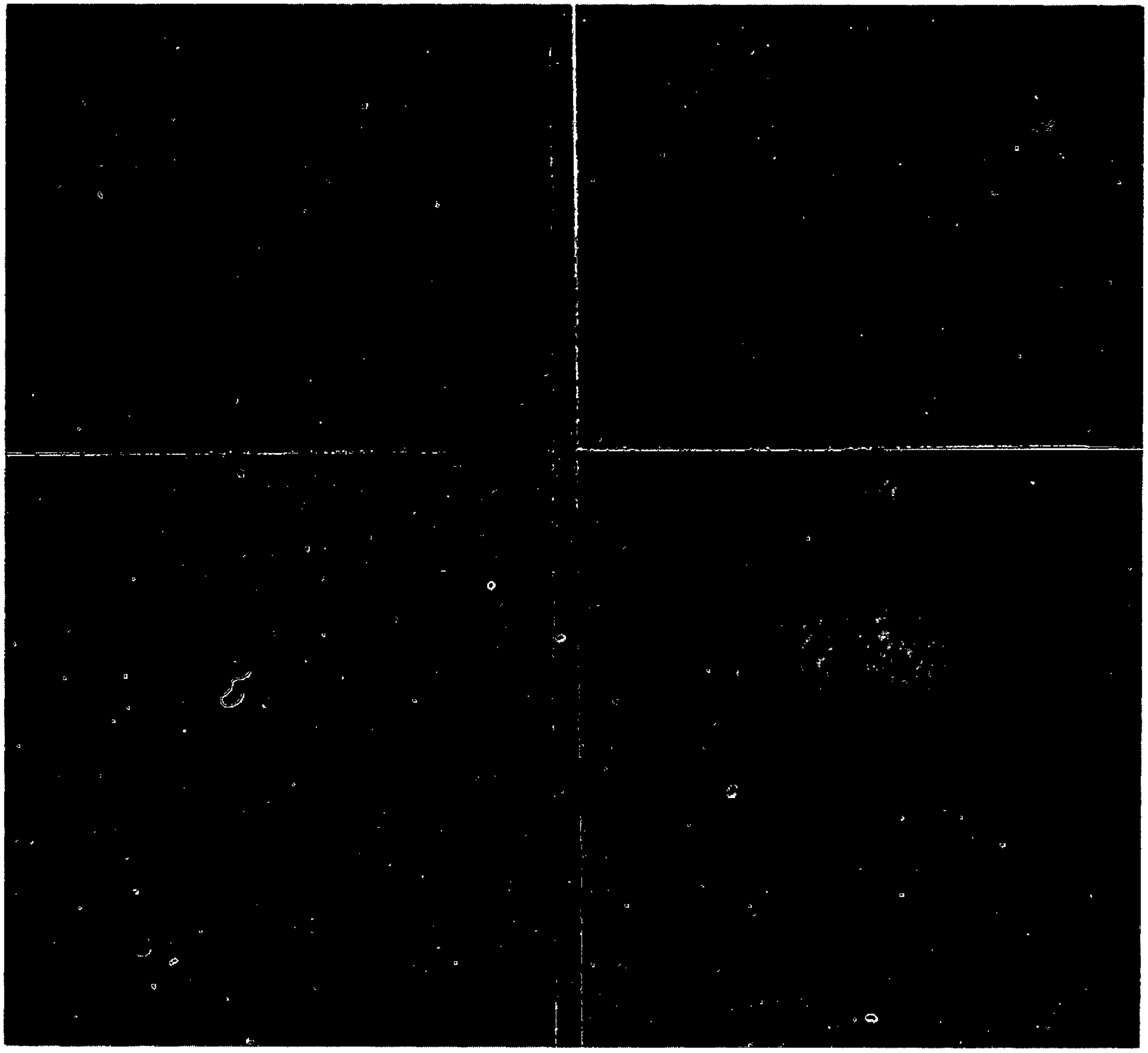
The IQ used in the density quantizing mode is suitable for the same general applications as the IDT. Although it lacks the four-color printout, the IQ has the advantage of much higher speed. The operator can run several traces in succession, and can quickly produce a trace that best enhances the particular information of interest. As different parts of a scene may require different density contour intervals to best facilitate interpretation, the ability to quickly produce such traces can be useful.

The IQ used in the derivative mode can also be useful when an analysis of the structure of low contrast imagery is desired. When viewed in conjunction with an enlarged image, and perhaps also a density-quantized trace, a derivative trace might indicate structure of interest that has been overlooked or provide additional information about a particular part of the image.

The IQ used in the derivative mode has also proved to be a fairly accurate mensuration tool. The density inflection point of an edge can be accurately and repeatably located on a derivative trace, and measurements of small objects made by measuring between the two inflection points on both sides of the object tend to be quite accurate.

Figures 1 through 3 illustrate how these properties of the IDT and IQ can be applied. Figure 1 shows photomicrographs of very low contrast three-bar groups of various frequencies. Figure 2 is a trace made with the IQ in the density quantizing mode; here we see some density structure within the bars and in the area surrounding the bars that is not readily apparent in viewing the image in Figure 1 directly. A trace made with the IDT would further emphasize this structure by printing out the equidensity contours in four colors. A comparison of Figures 1 and 2 shows that the IQ trace contains information that cannot be readily perceived by merely examining the image. For example, the IQ traces show that there is a density gradient in groups 3 and 4 from the lower left to upper right. The IQ trace also shows some structure within the bars in

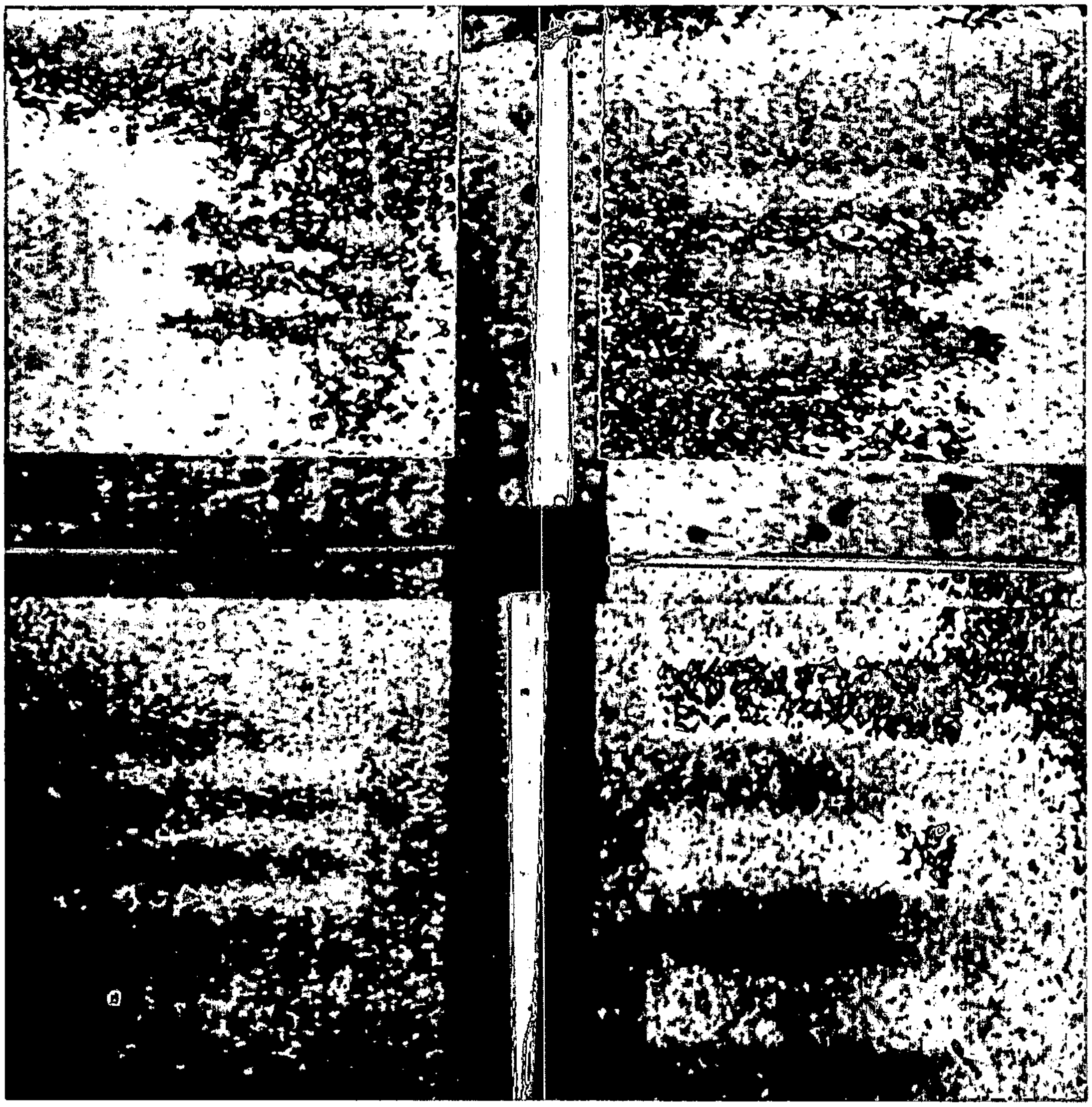
4 2



3 1

Figure 1. Photomicrographs of Low-Contrast Three-Bar Groups on Test Target

4 2



3 1

Figure 2. Traces of Figure 1 Made with the IQ in the Density Quantizing Mode with 0.8 mm Aperture

group 1 which is not readily apparent in the image. Whether or not this structure is significant is a decision that a human observer must make after comparing the IQ trace and the image with any a priori information he might have about the object. This example merely shows that low-contrast structure in a photographic image can be emphasized by an isodensity trace.

Figure 3, which is a derivative trace made with the IQ, shows how this type of trace can be used to locate edges. For group 4, for example, the positions of maximum density gradient in the edges of the bars cannot be accurately found from either the image or the IQ isodensity trace. These positions are emphasized by the derivative trace and can be much more reliably located. Again, the knowledge that these are three-bar groups, which is obtained from the original image, is necessary to allow the derivative traces to be interpreted properly.

OPERATING PARAMETERS

CHOICE OF A SCANNING APERTURE

In all instruments used for scanning photographic images, the scanning aperture is chosen so that it will provide the needed resolution but keep grain noise to a minimum. In a microdensitometer, slit apertures are often used when scanning objects containing long edges in a direction normal to the edges. The advantage of this type of aperture is that high resolution can be obtained by making the slit narrow in the scanning direction, and grain noise, which decreases as the total area of the scanning aperture increases, can be minimized by using a slit long compared to its width.

In two-dimensional scanning instruments we generally want to have the same resolution both parallel and normal to the direction of scan. This requires the use of symmetrical (square or circular) apertures. Slit apertures may be used in particular cases where it is desired to investigate objects with some degree of one-dimensional symmetry. Care must be taken in interpreting such traces since all shapes except edges parallel to the slit will be distorted.

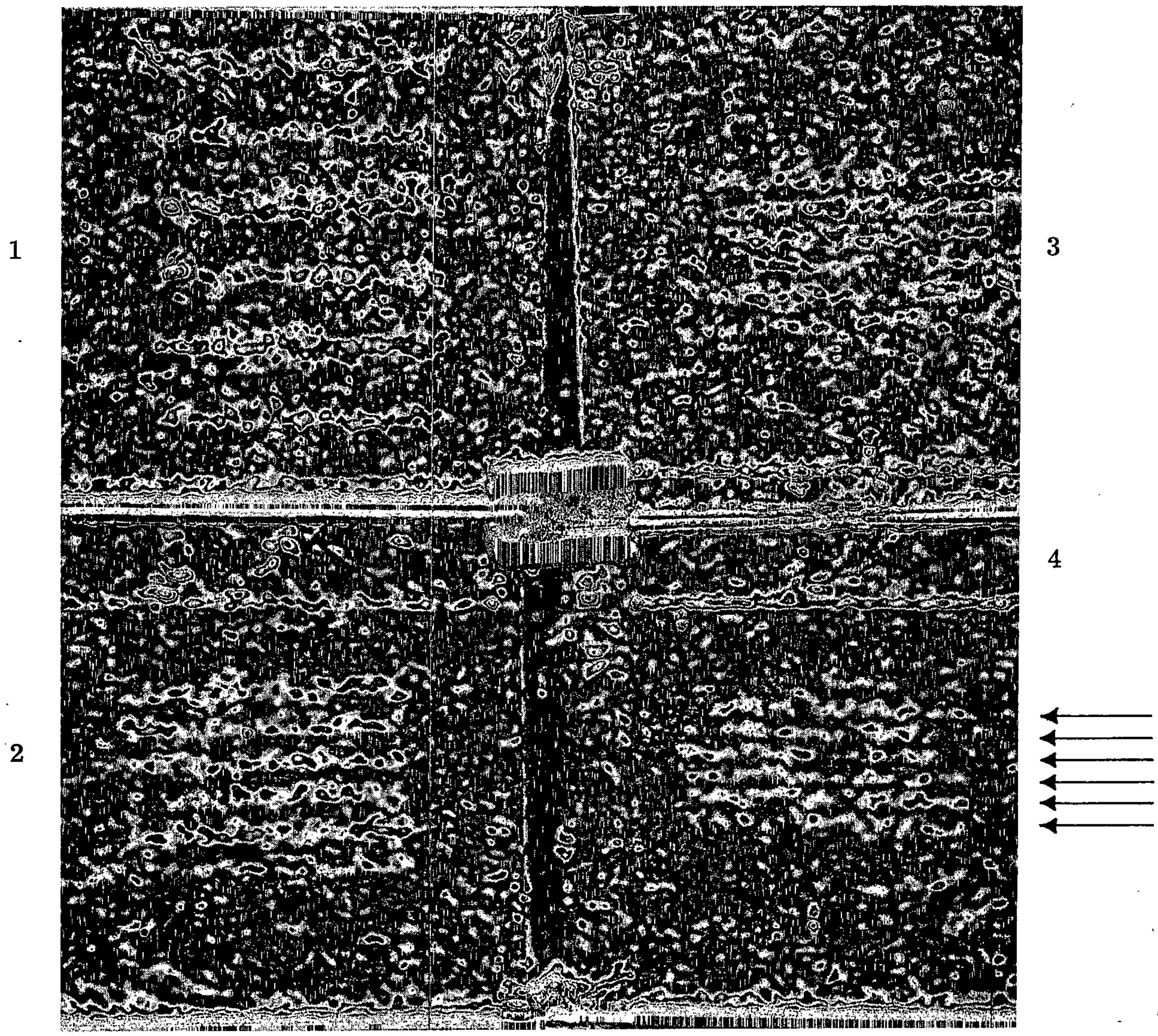


Figure 3. Traces of Figure 1 Made with the IQ in the Derivative Mode

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When symmetrical clear apertures are used, it is important that resolution is not "wasted" by using too small an aperture. Generally, the smallest aperture that should be used is one whose total width is half the smallest detail of interest.

Shaded apertures are advantageous whenever the use of a clear aperture that is by necessity made small to maintain the required resolution leads to an amount of grain noise that hinders interpretation. This is always the case when grain-limited imagery is to be analyzed. The optimum shaded aperture for use in these cases can be derived by computer. Although no shaded aperture is optimum in a mathematical sense when lens-limited imagery is to be traced, it might still be desirable to reduce grain noise so that a smaller density contour interval can be used. Shaded apertures can be tried in such cases, but there is no assurance that they will produce an improvement; here selection of the best aperture is somewhat of a trial and error proposition. A reasonable starting point is to use a shaded aperture having a half-power (in transmission) width that is equal to the total width of the clear aperture whose size has been determined by resolution requirements. If grain noise is still excessive, larger shaded apertures can be tried.

SPECIAL PROPERTIES OF THE IQ

When too large a scanning aperture is used in making isodensity traces in the IQ and IDT, the result is a spreading of the contours in areas of high frequency information such as edges or single bar images. When an edge is traced with the IQ in the derivative mode, however, spreading of the edge is noticeable as the aperture size is increased, but the position of the density inflection point does not change (see Figure 4). This effect can be useful when grain noise hinders mensuration based on the density inflection point method. The scanning aperture can be made larger than is necessary to "resolve" the object, and grain noise can thus be reduced without affecting the measurement accuracy.

Figure 5 shows the effect of changing the sensitivity setting of the IQ when it is used in the derivative mode. Higher sensitivity settings lead to an increase in the number of quantized derivative contours and, up to a point, allow a more precise

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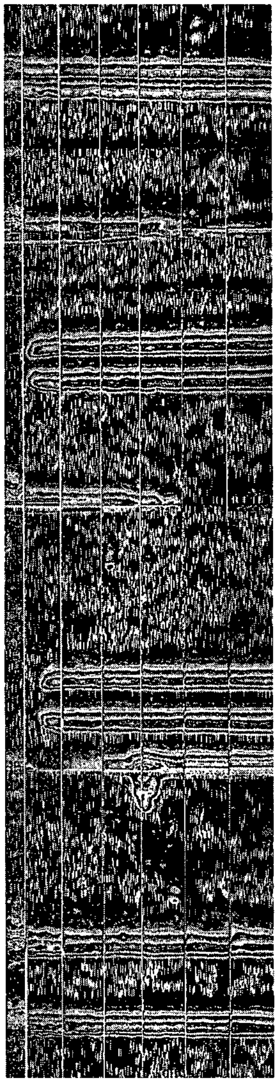

Figure 4. Traces of Single-Bars on Target Test Made With the IQ in the Derivative Mode Using Apertures of Different Sizes

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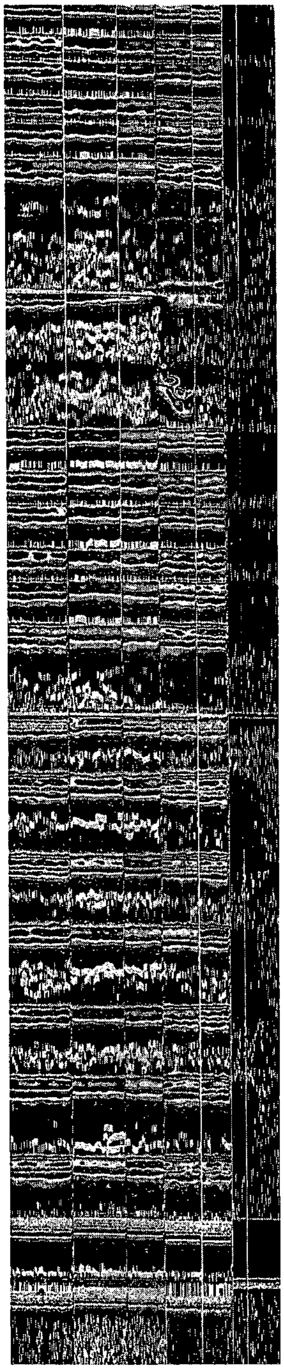

Figure 5. Traces of Three-Bar Groups Made with the IQ in the Derivative Mode and with a Time Constant of 0.01

determination of the inflection point. If the sensitivity is made too high, however, random fluctuations can lead to some ambiguity in the inflection point location.

THE PROJECTION PRINTER

The degree to which photographs should be enlarged in the Projection Printer for use in the IQ will depend on several considerations. For most work, a magnification that enlarges one resolution element on the original to 2 mm on the photomicrograph will be satisfactory. The photomicrograph can then be scanned with the smaller apertures in the IQ with the assurance that the original details will be well resolved, or with the larger apertures to provide minimum grain noise while still resolving the original details. Larger magnifications can be used when resolution is a critical factor, and smaller magnifications can be used when the main requirement is scanning large areas in a short time.

The film used to make photomicrographs should normally be of low contrast ($\gamma = 1.0$ or less) and high speed. Tri-X film with Microdol-X developer is recommended. The exposure should be made so that the original scene is exposed as much as possible on the linear part of the H and D curve of the recording material. Higher contrast films can be used if structure of very low contrast is to be analyzed.

Vibrational stability of the instrument is critical at very high magnifications (250X and up). Placing the unit on a stable surface such as a granite slab will minimize this problem.

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